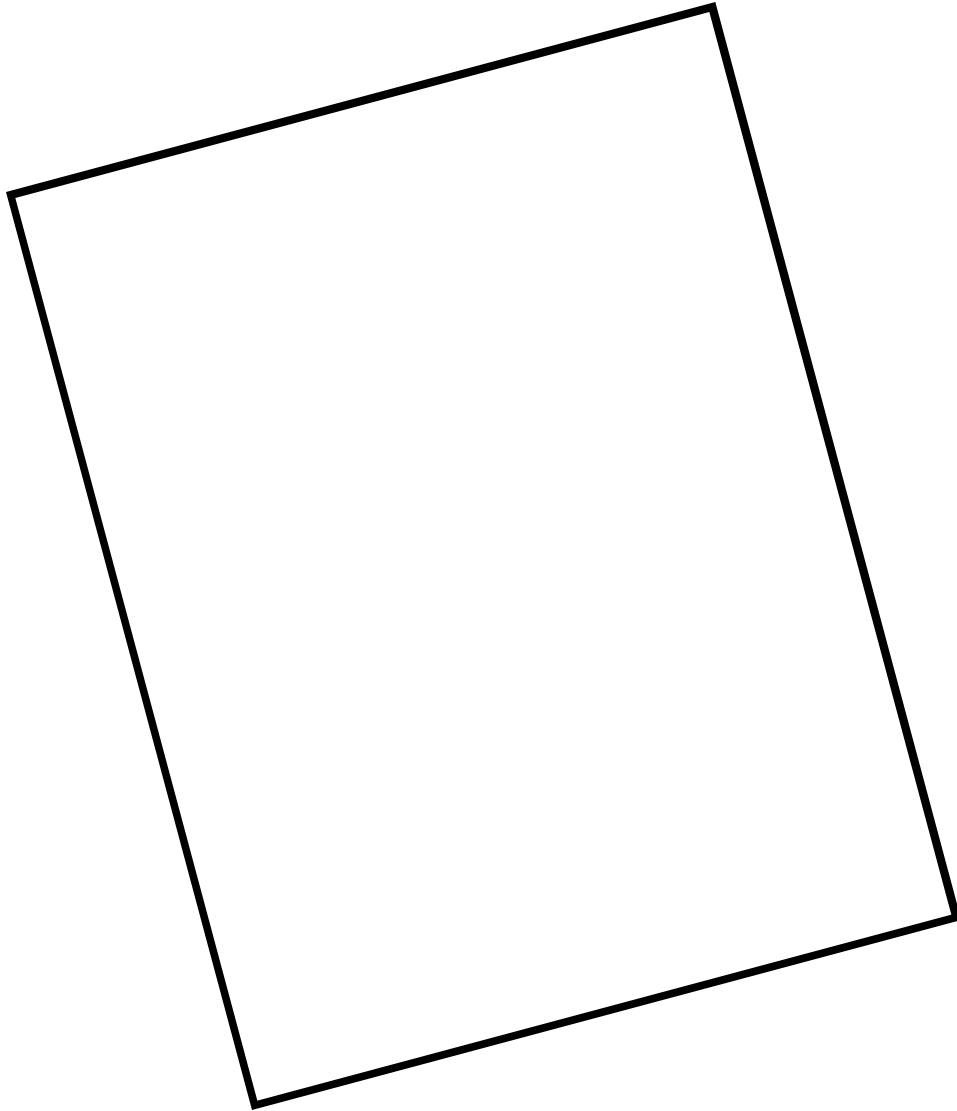




SOURCE ENERGY AND
ENVIRONMENTAL
IMPACTS OF THERMAL
ENERGY STORAGE

FEBRUARY 1996
CALIFORNIA
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COMMISSION



Prepared for:

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A full list of Collaborative members is included in the Appendix.

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Foreword

The purpose of the Opportunity Technology Commercialization (OTCOM) program of the California Energy Commission is to “effectively increase the market penetration of energy technologies offering compelling energy, environmental, diversity and economic development benefits. “OTCOM selected Thermal Energy Storage (TES) as one such technology. TES allows cooling made at night to be stored for building air conditioning during the day.

To promote TES (as other technologies), OTCOM organized a Collaborative of utilities, consultants, proactive facility managers and TES product manufacturers. The Collaborative suggested the first key item of business was authoritatively analyzing the source energy¹ and other environmental benefits of TES in California. The Collaborative believed that one major obstacle to TES was a perception that TES increased energy use and increased environmental emissions. Therefore, the Collaborative decided an authoritative analysis on this issue in California was a necessary and desirable first step.

The Collaborative selected Tabors Caramanis & Associates to conduct this analysis for California with review by other respected organizations, such as those listed in the Acknowledgments. This report contains the results of this analysis. Based on the source energy and environmental results, the report also identifies possible policy actions by key energy and environmental policy makers.

¹ In California the “source energy” use of electrical equipment is defined as the BTU’s of primary fuel required at the electric generating plant (or power plant) to run this electrical equipment

Executive Summary

The Thermal Energy Storage (TES) Systems Collaborative organized by the California Energy Commission requested an analysis of the source energy (power plant fuel) savings of electric Thermal Energy Storage (TES) systems in California. The Collaborative also requested an analysis of other TES impacts of concern to the Commission:

- Site energy (kWh) savings
- Air emissions savings
- Economic development or competitiveness

Energy Analysis

Source Energy Analysis

In analyzing the source energy use of TES, the study focused on the two largest electric utilities in the state — the Pacific Gas and Electric Company (PG&E) and the Southern California Edison Company (SCE) — which supply almost three-fourths of the electricity in the state. Two methodologies were used in this study. The first methodology — the “Incremental Energy method” — applied the standard planning methodologies used in California.¹ The second methodology — the “Marginal Plant method” — was a variation of the Standard California methodologies.²

The results of the methods showed that the source energy savings for a particular TES system at a particular building depend on a number of factors, including:

- The building’s normal air conditioning usage pattern without TES (e.g., what percent of the cooling is summer vs. winter or day vs. night)
- The design and operating strategy for the TES system (e.g., is the TES storage tank sized so that the air conditioning compressor runs only at night — full storage — or runs all day long — partial storage)³
- The characteristics of the utility supplying the electricity (e.g., amount of hydro power available)
- The methodology used — in particular, whether the savings from reduced “unit commitment” are included.⁴

Source Energy Savings of TES from Load Shifting
(ignoring kWh savings)

| | <u>SCE</u> | <u>PG&E</u> |
|---------------------------|------------|-----------------|
| Incremental Energy method | 36% - 43% | 20% - 30% |
| Marginal Plant method | 12% - 24% | 8% - 10% |

In many California TES installations, 40 percent to 80 percent of the annual kWhs of electricity use for air conditioning will be shifted from day to night. In such installations the official Commission methodology, the Incremental Energy method, showed significant source energy savings. The savings per kWh shifted range from 36 percent to 43 percent for SCE and 20 percent to 30 percent for PG&E. The savings from the Marginal Plant method were lower *but still substantial*— 12 percent to 24 percent for SCE and 8 percent to 10 percent for PG&E. This means that even if some TES systems used more kWhs than conventional air conditioning, such TES systems could still yield a net source energy savings.

If TES achieved a 20 percent market penetration by 2005⁵, enough source energy would be saved from load shifting only (ignoring kWh impacts) to supply the energy needs of over a fifth of all new air conditioning growth projected by the Energy Commission during the next decade. From another perspective, TES could save enough source energy to supply all electric cars projected by the Energy Commission to exist in the state in 2005. These are potential fuel savings to the state of California.

Aggressive use of TES can save
enough source energy to supply

All 500,000 electric cars added in the next decade.

Site Energy Analysis

TES systems can notably improve energy efficiency over conventional air conditioning systems. Although early TES systems used more kWhs than conventional

systems, monitoring of many recent TES systems shows these systems use 12 percent fewer kWhs than conventional systems. These efficiencies are also attractive compared to the 20 percent to 50 percent energy penalties from using conventional utility storage technologies such as pumped hydro. Improving TES efficiencies reflect increased experience in applying some of the distinctive advantages of the TES technology.

Source and Site Energy Analysis Combined

When the site energy savings are combined with TES source energy savings noted above from shifting load, TES can achieve considerable energy savings. In particular, again assuming a 20 percent market penetration by 2005, TES could save enough energy to supply over a third of the new air conditioning load projected by the Energy Commission.

Environmental Analysis

Source Emissions Analysis

TES also provides a number of environmental benefits. TES can also help reduce combustion air emissions. The South Coast Air Quality Management District (SCAQMD) explicitly identifies thermal storage as one way to reduce site emissions.⁶ TES, however, can also reduce air emissions from power plants. Indeed, in California where natural gas is usually the fuel of the marginal power plant, the reductions in power plant emissions are comparable to the energy savings from TES.⁷ Assuming a 20 percent market penetration by 2005, TES could save 260,000 tons of CO₂ annually statewide. Just as importantly it could save about 1.6 tons of NO_x per day in the SCAQMD. These NO_x savings are equivalent to the savings from almost 100,000 electric vehicles.

TES can Reduce Air Emissions

* At the Power Plant Source

TES could save 260,000 tons of CO₂ annually statewide. It also could save 1.6 tons of NO_x per day for the SCAQMD — equivalent to almost 100,000 electric vehicles.

* At the Building Site

TES can help reduce CFC's and combustion emissions.

Site Emissions Analysis

TES can help in the transition to air conditioning refrigerants without CFC's. For example, when

existing chillers are converted to a non-CFC refrigerant, the chillers effective cooling capacity may be reduced. Some key facility managers see TES as making up the difference. In addition, partial storage TES systems often can require half as much chiller capacity, which means half as much refrigerant is necessary.

Economic Development/Competitiveness

TES enhances the competitiveness of both California energy suppliers and building owners. Both are discussed further.

TES promotes Competitiveness or Economic Development

» For Energy Suppliers statewide*, TES provides:

- lower costs (30 percent to 50 percent lower to serve air conditioning load)
- reduced financing requirements (\$1-2 billion)
- improved customer retention

» For Building Owners statewide*, TES provides:

- lower costs (over half billion dollars annually)
- increased property values (\$5 billion)
- increased financing capability (\$3-4 billion)
- increased revenues

*Statewide numbers assume a 20 percent market penetration of TES.

Energy Supplier Competitiveness

Several factors work to enhance the energy supplier's competitiveness. For example, the marginal cost of serving a customer's air conditioning load can be decreased by 30 percent to 50 percent. In addition, electric utilities are about five times more capital intensive than other manufacturing businesses per dollar of revenue. Therefore, improving the customer's load factor by 30 percent to 50 percent with TES can mean a significant reduction in the financing requirements and financial exposure from serving TES customers. Financing requirements could be reduced a billion dollars in Transmission and Distribution system and perhaps comparable savings in generation capacity. Finally, the ability of TES to lower the average price to a customer provides another customer retention tool for energy suppliers.

TES' Value to Energy Suppliers Should Increase in a Competitive Electricity Future

* The Electric Power Industry is considerably more capital intensive than most other industries.

* Historically under “rate base” regulation, utilities had an incentive to increase capital investment.

* Under the emerging competitive markets and Performance Based Rate making, energy suppliers will minimize capital investment.

* TES improves load factor and capital efficiency better than most DSM programs — while accomplishing environmental benefits.

Building Owner Competitiveness

The competitiveness of California building owners can also be enhanced. For example, the building owner can have lower energy and other costs (e.g., chilled water storage tanks can lower fire insurance premiums). Moreover, some commercial facilities managers believe that TES could be the best tool available for lowering power costs in a re-structured electricity industry. In addition, because TES increases the property value, the building owner can often obtain more external financing on a project and use less of the developer’s own cash. Finally, the building owner can increase revenues with TES — cold air distribution systems allow more floors of leasable space and, hence, greater revenues. These factors work to enhance the building owner’s competitive position in California.

TES is the best tool a commercial facility manager has for managing power costs under Real-Time Pricing, which the CPUC has proposed as the dominant type of pricing in a re-structured electricity industry.

—Bill Kane, Energy Management Coordinator,
San Francisco Moscone Marriott Hotel

—Ted Bischak, Senior VP, Tooley & Co., which manages
several million square feet for The Irvine Company

Possible Policy Actions

Based on the energy savings and other benefits of TES, several possible policy actions emerge for consideration. The first possible policy action is deeming TES as a priority energy efficiency or Demand-Side Management program in state energy resource policy decisions. TES has demonstrated considerable energy and air emission savings like other energy efficiency programs. But unlike most energy efficiency measures, TES measurably improves load factor and provides cost savings that help both energy users and energy suppliers be more competitive.

- Possible Policy Actions to Promote TES
- Deem TES a priority DSM technology in energy policy decisions.
- Modify Title 24 Building Standards to reflect TES’ source energy savings and peak demands reductions.
- Use TES as an air emissions control measure statewide.
- Identify TES as a priority option for new and replacement cooling systems in “competitive energy environmental partnerships” with key energy users, such as:
 - local, state, and federal buildings, and
 - businesses striving to be environmental leaders, as in the EPA’s Energy Star Program.

The second possible policy action is to modify the State of California Title 24 Building Standards method of comparing alternative cooling technologies’ energy efficiencies. The Commission could re-examine the role of source energy comparisons of alternative systems including the opportunities of TES systems. In addition, as in Switzerland⁸, the building code could encourage designers to lower the building peak demands with TES.

The third policy action is recognizing TES as an effective air emissions control measure. The South Coast Air Quality Management District has recognized thermal storage as a way to reduce site emissions.⁹ Other air districts could follow suit. In addition, many California air districts would benefit from encouraging TES as a control measure for power plant emissions.

The fourth policy action is promoting TES as a priority cooling system option in “environmental partnerships” with key energy user groups. One such group could be “sister” governmental agencies of the Commission, including local, state and possibly federal government agencies. Another possible group includes businesses striving to be “environmental partners.” As an example, the US Environmental Protection Agency has had considerable success in obtaining business “environmental partners” in its Energy Star programs such as Green Lights. This program has obtained a number of business partners in California who have committed to installing high efficiency lighting in 90 percent of their floor space over a five year period when the internal rate of return (IRR) exceeds 20 percent. California could develop a “Competitive Electricity Environmental Partnership” program for TES that is modeled after the Energy Star program. This partnership would position California businesses to benefit

from a competitive electricity market and help clean the air as well. Alternatively, perhaps TES could be included as a priority cooling technology in the second phase of the Energy Star program — which moves from lighting to heating and air conditioning system improvements.

Sample Organizations in
EPA Energy Star/Green Lights Program
that have a Significant California Presence

| | |
|----------------------------------|---------------------------|
| • Allergan* | • Long's Drugs |
| • ARCO | • McDonald's* |
| • Bank of America* | • Rockwell* |
| • Calif State University System* | • SCAQMD |
| • State of California* | • The Shorenstein Company |
| • Chevron* | • TransAmerica |
| • Embarcadero Center* | • Wal-Mart* |
| • Hewlett Packard* | • Walt Disney Studios* |

*Organizations with TES installed in at least one site.

In summary, this study demonstrates that TES is an “energy technology offering compelling energy, environmental, diversity, and economic development benefits to California.” Moreover, TES is poised for full commercialization. Institutional policies, such as those previously identified, can be pursued to “effectively increase the market penetration” of TES — as the Energy Commission desires.

Chapter End Notes

¹ As discussed in more detail in Section 2, the “incremental energy” methodology applies the state’s official methodology (as used by the Public Utilities Commission, Energy Commission, and utilities) for marginal cost calculations and resource planning (including Demand-Side Management programs such as TES) to the state’s official guidelines for source energy analysis to develop time-differentiated source energy impacts. These impacts allowed the determination of source energy savings by shifting electricity usage from day to night with TES.

² The “marginal plant” method is similar to the state’s official methodology with one exception. It has a different way of computing marginal source fuel use in different time periods. This alternate methodology is also described in Section 2.

³ This study assumes that TES is operated under conventional Time-of-Use rates. Some studies have found that for thermal storage operating with intelligent control systems under hourly varying Real-Time Pricing, the utility’s marginal energy cost savings (and presumably source energy savings) were up to double the savings for thermal storage operating under conventional Time-of-Use rates. (See, B. Daryanian, L.K. Norford, and R.D. Tabors, “RTP Based Energy Management Systems: Monitoring, Communication, and Control Requirements for Buildings under Real-Time Pricing.” ASHRAE Transactions 1992, V.98, Pt. 1.) The California Public Utilities Commission recommends Real-Time Pricing as the dominant type of pricing in a competitive or re-structured electric power industry. Therefore, the source energy savings of TES under the increasingly more common Real-Time Pricing could be significantly higher than the source energy savings reported here.

⁴ The main difference between the two methods is that the “Incremental Energy method” captures the fuel savings from reduced need for “unit commitment” — “committing” a power plant “unit” to run much of the day to be available to meet daily peak demand.

⁵ PG&E conducted an internal study, *Off-Peak Cooling Market Potential Study*, that conservatively estimates 20% as an achievable market penetration for TES.

⁶ These savings take place when a heat recovery storage system is used with cool storage system to use heat from the chillers in lieu of a separate boiler.

⁷ As discussed in Section 3, the difference in emissions costs for day vs. night are greater than the difference in source energy use. However, some of that difference is due to emissions being generated in different air basins. Therefore, to be conservative, the conclusion is that air emissions reductions are at least as great as the source energy and site energy savings combined — 20 percent to 40 percent per kWh of annual cooling energy (using the “incremental energy” method), depending on the TES system application.

⁸ For example, the Geneva Electric Utilities Article 117A requires in any building over 10 kW demand that “the installation must be designed to limit the maximum needed power by cutting excessive thermal charges.” Moreover, the designs reviewed by a commission must analyze the possibility of thermal storage and waste heat recovery.

⁹ South Coast Air Quality Management District, 1994 *Air Quality Management Plan. Appendix IV-A, Stationary Source Control Measures*. “Area Source Credit Program for Commercial and Residential Combustion Equipment [NO_x].”

Section 1

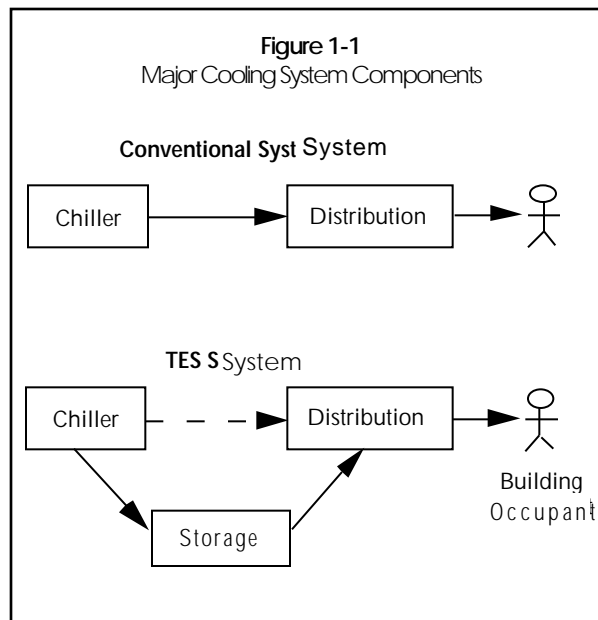
What is Thermal Energy Storage?_____

Thermal Energy Storage is a technology that stores “cooling” energy in a thermal storage mass.¹ As Figure 1-1 shows, the storage mass can be a third major component of an air conditioning or cooling system in a building. In most conventional cooling systems, there are two major components:

Chiller — to make water or some other fluid cool

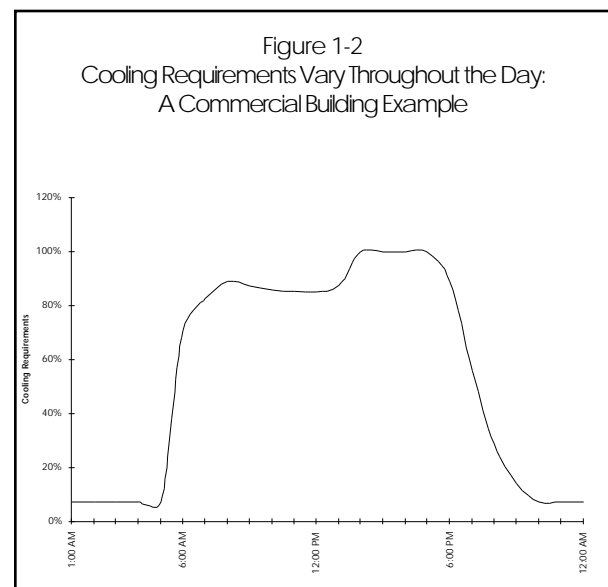
Distribution system — to take the cool water (or fluid) from the chiller to a place where it cools air for the building occupants.

In conventional systems, the chiller must be run whenever the building occupants want cool air. In a storage cooling system, the chiller can be run at times other than when the occupants want cooling.



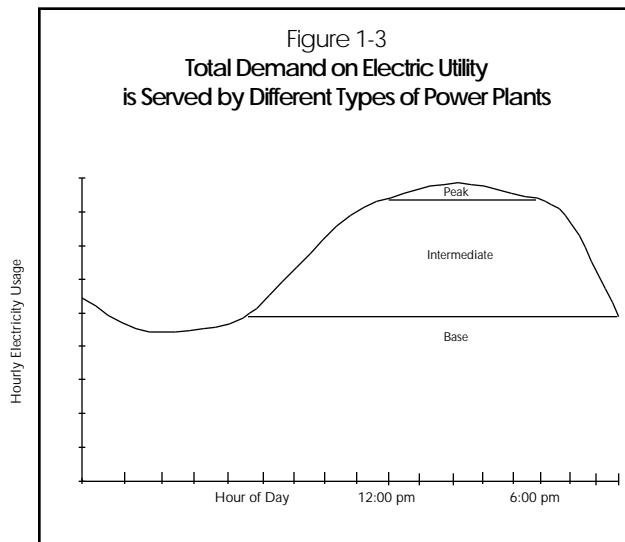
There are some advantages to being flexible as to when the chiller can run, since the chiller is typically the most energy intensive part of a cooling system. For example, Figure 1-2 shows the amount of cooling desired at

various hours of the day in a typical commercial office building. Not surprisingly, the cooling demands are highest when the building is occupied and when the outside temperature is hottest during the afternoon. In a conventional cooling system the electricity use follows the demand for cooling — since the chiller must run to cool the building.

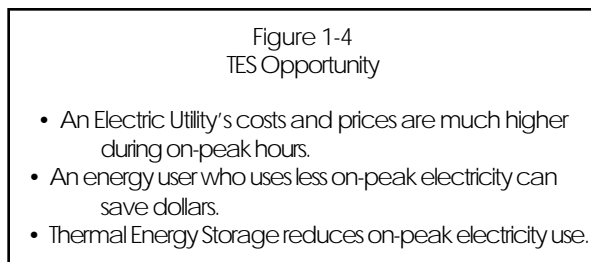


Air conditioning (and industrial process cooling) makes up almost a third of the aggregate electricity demand on California utility systems during the summer. Therefore, the aggregate utility demand tends to have the same pattern as a building’s cooling demand. Compare Figure 1-3 to Figure 1-2. Moreover, to keep over-all electricity costs down, electric utilities run their most economic (and typically most efficient) “base load” power plants as much as possible. Other power plants are somewhat less efficient. These “intermediate” power plants see limited use during the day. Finally, plants with the highest operating costs (and typically

lowest efficiency) are mainly used during the few “on-peak” hours. Hence, they are called “peak” load power plants or sometimes just “peakers.”

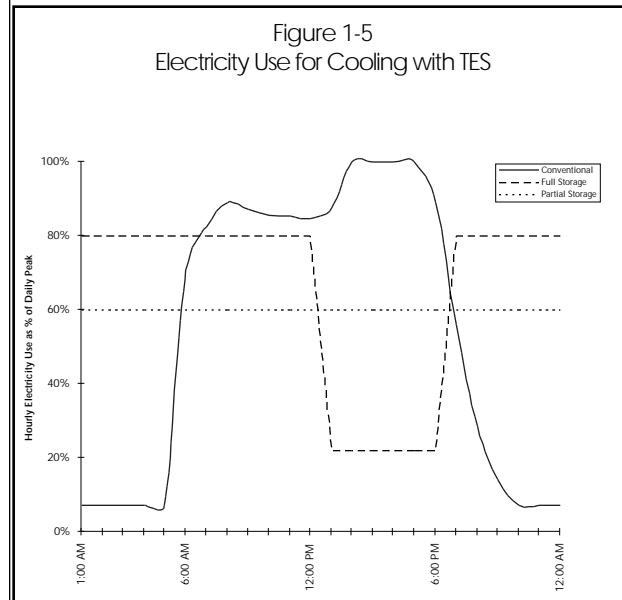


The cost to produce a kWh of electricity is highest during these on-peak hours. Two factors contribute to these high costs. First, the California utilities must build enough capacity to meet the highest or peak demand. Therefore, much of the utility’s capacity related costs are charged during these on-peak hours (often as peak “demand” charges). Second, because the least efficient power plants run during the on-peak hours, the costs of generating the electrical “energy” are higher during those hours. This leads to a situation in which electricity users can reduce their electricity costs under Time-of-Use² rates if they can reduce their peak electricity use. TES provides electricity users that opportunity, as Figure 1-4 summarizes.



There are typically two basic strategies for using TES to reduce on-peak electricity use, as Figure 1-5 shows. The first strategy, “full storage,” sizes the chiller and storage tank so that the chiller does not run at all during the peak hours even on the hottest days. In contrast,

the “partial storage” strategy sizes the chiller and storage tank so that a smaller chiller runs continuously on hot days. The main advantage of the “full storage” system is that it minimizes electricity costs. The main advantage of the “partial storage” system is that a smaller chiller and smaller storage tank reduce the capital costs of the TES system.



To achieve these strategies, five major types of TES systems usually are used, as Figure 1-6 shows. The first type uses “chilled water” as the storage medium. It has the advantage of being compatible with existing chillers and probably being the most energy efficient storage system. It has the disadvantage of requiring much larger storage tanks than the other storage media.

The second type of TES system uses a “eutectic salt” water solution as the storage medium. Eutectic salt systems store cool by freezing the solution at a temperature typically near 47°F. This gives these systems two major advantages. One, by storing cool through a phase change (freezing) smaller tanks are required than for chilled water. Two, freezing at 47°F, standard chillers producing 41°F chilled water in commercial facilities can be used. The biggest disadvantage is that the tank typically cools the water for the distribution system to only 48-50°F, which accomplishes less dehumidification of the building and requires more pumping energy.

Figure 1-6
Major TES Cooling System Options

| Chiller ³ | Storage | Distribution |
|----------------------|-------------------------|-------------------|
| 1. Conventional | <i>Chilled Water</i> | Conventional |
| 2. Conventional | Eutectic Salt | Conventional |
| 3. Ice | <i>Ice</i> ⁴ | Conventional |
| 4. Ice | <i>Ice</i> | Cold Air |
| 5. Ice | <i>Ice</i> | Unitary (Rooftop) |

The next three storage systems have one thing in common — ice as the storage medium. They differ in how the “cool” from the ice is distributed to the building occupants. Before considering the differences in the distribution systems, consider the features of their common components — ice storage and chiller. The main advantage of ice systems is their compact storage size — ice tanks may be only 10 percent to 20 percent and 30 percent to 50 percent of the size of comparable chilled water and eutectic salt tanks, respectively. For many commercial developers where space is a premium this can be a real advantage. Another major benefit when used with cold air or rooftop distribution systems are the significant dehumidification benefits and fan energy savings. The major disadvantage of ice systems is that most conventional chillers that chill water cannot be used — special chillers capable of making ice must be used. Ice chillers use more energy than conventional water chillers because of the lower temperatures required to freeze water into ice.

Ice storage systems can be used with conventional chilled water distribution systems. Ice storage systems, however, are particularly beneficial when the distribution system has been designed to take advantage of the colder water to produce “cold air.”⁵ The distribution system (fans and ducts) can be down-sized which leads to three major benefits. First, the initial cost of the distribution system is lower. Second, the energy use by the distribution system is lower — fan and pump energy use may be lower by 40 percent or more.

Third, smaller ducts can mean lower floor-to-floor heights in high rise buildings — which allows architects to design additional floors without increasing building height and lower the net cost per square foot of floor space.

The first four TES systems listed in Figure 1-6 are used mostly with typical chilled water distribution systems in larger buildings. The third type of storage system is used with unitary systems. Unitary systems include those used with typical single-family residences with an outdoor condensing unit and indoor coil with a gas furnace or electric heat, or heat pumps and air handler. Unitary systems also include single-package systems that are roof mounted on low-rise commercial buildings and, in certain geographical locations, some residences. These unitary systems use a “direct expansion” process where the refrigerant, not chilled water, cools the air that is delivered directly to the occupied structure. These smaller unitary systems are typically air cooled and are generally not as efficient as most of the water-cooled chilled water systems used on larger buildings. Because of the usually lower efficiency of these air-cooled unitary systems, these systems maybe an attractive target for the next wave of TES installations.

Another attraction is that because these unitary systems run fewer hours, they leave residential and small commercial customers with poor load factors which are more costly for utilities to serve. Since a high proportion of utility capital expenditures are used to provide T & D systems for these customers, using TES to improve their load factors can save capital dollars.

This concludes a brief description of TES, its benefits to the energy user, the California electricity supply system, and the five main types of TES system technologies. The next section analyzes the source energy use of TES.

Chapter End Notes

ChapterReferences:

Electric Power Research Institute, *Commercial Cool Storage Primer*, EM-3371, 1984.

Electric Power Research Institute, *Commercial Cool Storage*, CU. 3024, 1988.

Electric Power Research Institute, *Thermal Energy Storage*, CU. 2036, 1992.

ASHRAE, *Design Guide for Cool Thermal Storage*, 1993.

¹ The term “Thermal Storage” usually includes systems that store heat as well as store cool. In California the primary use for storage is cool storage because of the dominant summer electricity peaks due to air conditioning. In this report, Thermal Energy Storage implies cool storage.

²Time-of-Use rates are utility service options in which the price varies by the “time-of-use.” In particular, in California prices are highest during the summer weekday afternoons and lowest at nights and weekends.

³ Electrical centrifugal or gas absorption chillers are typically the conventional water chillers. Electrical reciprocating, screw scroll or multi-stage centrifugal chillers and gas reciprocating chillers are normally used to make ice.

⁴ There are several types of ice storage systems including ice harvester, external melt ice, internal melt ice, and encapsulated ice. For simplicity they are combined here. For more detail on each, see ASHRAE’s “Design Guide for Cool Thermal Storage.”

⁵ Ice systems typically discharge water at 34-38°F from the storage tank which supplies “cold air” at 42°F to the occupant space. In contrast, conventional systems send water into the distribution system at 40-44°F which supplies air at 55°F into the occupant space. Please note that some chilled water storage tanks may be super cooled to also discharge water at 36-38°F.

Section 2

Source Energy Analysis

A major focus of this study is determining the increase or decrease in energy use at the source due to Thermal Energy Storage (TES). The general belief is that TES reduces the fuel or energy required at the source by changing the time at which kWhs of electricity are used. This study tests that belief by quantifying the source energy impact of TES.

Two methodologies for determining source energy impacts are first defined. Then the methodologies are applied to California's two largest utilities, SCE and PG&E, which together supply almost three-fourths of the electricity in the state.

Methodology

Two methods were developed for calculating source energy savings

- Incremental Energy method
- Marginal Plant method

The Incremental Energy method is the most consistent with existing planning methods in California. The Marginal Plant method is fairly consistent with the Incremental Energy method, but with one major difference — its energy savings are based on system lambda which does not recognize the energy use associated with unit commitment.¹

The following fully describes the Incremental Energy method development followed by the Marginal Plant method, with emphasis on its major difference with the Incremental Energy method. Finally, this major difference — the inclusion of unit commitment savings in the Incremental Energy method — is discussed.

Incremental Energy Method

In defining the methodology for this study, the first source of guidance was the standard planning methodologies used in the state of California. In particular, several accepted standard methodologies guided the

development of this study's methodology. The first was the use of "marginal" costs (rather than average costs) for all resource planning and rate design decisions. That is, the decision about which resource to use is based on how the costs of providing power would change for a marginal or incremental change in electricity use beyond current usage levels. The California Public Utilities Commission (CPUC) and the Energy Commission also believe that the marginal costs should be reflected in the design of electric rates so that the energy users get a proper price signal that will lead to wise use of energy resources in the state.

From this perspective, a Standard Practice Methodology² has been developed for evaluating the cost-effectiveness of both new supply resources and demand side (or Demand-Side Management — DSM) resources. DSM resources reflect the perspective that energy efficiency programs (aimed primarily at reducing the kWh use) and load management programs (aimed primarily at reducing the kW of peak demand) can be considered as the equivalent of a special type of supply-side resources in resource planning decisions. The Standard Practice Methodology evaluates DSM programs by comparing the kWh and kW savings against the marginal cost (of supply) for providing those kWh's and kW's. This Methodology has gained national and international acceptance as a rational way to evaluate DSM programs — including TES.

One key feature of the Standard Methodology for evaluating TES programs is that it divides the year into time periods— and differentiates the marginal costs (both kW and kWh) by time periods. Figure 2-1 shows how SCE and PG&E currently divide the year into five time periods. Note that both SCE and PG&E define the summer on-peak period as being (working) weekdays from noon to 6 p.m. The two utilities' definitions of mid-peak and off-peak differ slightly. Note that there is no winter on-peak period because of the dominance of the summer peak in determining new

(marginal) capacity decisions. Finally, note that SCE defines a four-month summer whereas PG&E defines a six-month summer. The number of summer months will later influence the source energy results.

| Figure 2-1 Five Time Periods Used in the Standard Practice | | |
|---|--------------------------------|----------------------------------|
| | SCE | PG&E |
| Summer Months: | Jun - Sept | May - Oct |
| On-Peak Weekdays: | 12-6 pm | noon - 6 pm |
| Mid-Peak Weekdays: | 8 am - noon 6 pm - 11 pm | 8:30 am - noon 6 pm - 9:30 pm |
| Off-Peak | all other hours, inc. holidays | |
| Winter Months: | Oct - May | Nov - April |
| Mid-Peak Weekdays: | 8 am - 9 pm | 8:30 am - 9:30 pm |
| Off-Peak | all other hours, inc. holidays | |

The core formula for the Standard Practice methodology is shown in Figure 2-2. Note that the annual dollar savings of resource benefits of a DSM program is computed by determining the kWh and kW savings in each of the five time periods, multiplying those savings by the marginal cost for that time period, and then summing the dollar savings across all time periods.

| Figure 2-2 The Standard Practice Core Formula | |
|--|--|
| $\text{DSM Program Savings} = \sum_{i=1}^5 (\text{kWh Savings})_i \times (\text{Marginal Cost of kWh})_i + \sum_{i=1}^5 (\text{kW Savings})_i \times (\text{Marginal Cost of kW})_i$ | |

Recently the CPUC (with Commission concurrence) has modified the Standard Practice to provide some guidelines on source energy analysis. In particular, the CPUC was faced with the decision of how to evaluate the appropriateness of “fuel substitution” programs — that is, programs designed to have a customer substitute a technology using one “fuel” with a technology using a different “fuel.” An example of this is encouraging heat pumps to replace gas furnaces (or vice versa). As part of the fuel substitution guidelines, the CPUC developed a source energy test. The CPUC said that,

among other things, for a fuel substitution program to be acceptable, it could not use any more BTU’s of source fuel than the fuel it was replacing. Moreover, the CPUC defined the “source BTUs” of electricity to be those fuel BTUs used at the power plant to generate electricity.³

The CPUC also said the way to equate source BTUs of natural gas with source BTUs of electricity was to use the Commission’s official annual average electric power plant “heat rate” contained in the Title 24 Building Efficiency Standards (10,239 BTUs/kWh). For most DSM programs, using an annual average number is acceptable for determining source energy savings. However, for TES it is not. The CPUC has previously not needed to modify the source energy method for TES because TES was considered a “load management” program rather than a “fuel substitution” program — and source energy calculations are not required for load management programs.

Personal communication with CPUC staff reveals an acceptable way to modify the Standard Practice method and numbers to develop source energy savings estimates of TES programs.⁴ In particular, the “marginal cost of a kWh” is often called the “marginal energy cost.” This cost (in \$/kWh) for each of the five time periods equals the cost of fuel (in \$/BTU or usually \$/million BTUs) multiplied by the average heat rate or more precisely Incremental Energy Rate (in BTU/kWh). Since natural gas is almost always the fuel of the marginal plant,⁵ dividing the marginal energy cost for each of the five time periods by the price of natural gas yields the average Incremental Energy Rate (in BTU/kWh) for each of the time periods, as shown in Figure 2-3. In fact, SCE explicitly makes such a calculation as part of its materials submitted to the CPUC in calculating marginal energy costs for rate design.⁶

This Incremental Energy Rate perspective can be applied to the Standard Practice’s Core Formula in Figure 2-2 to develop a formula for calculating source energy savings. In particular, dividing all marginal energy (kWh) cost terms in the formula in Figure 2-2 by the marginal fuel price (\$/BTU) yields the formula in Figure 2-4 for calculating source energy savings.⁷

| Figure 2-3 Determining the Incremental Energy Rate | |
|--|--|
| <p>For each of the five time periods,</p> $\text{Incremental Energy Rate (BTU/kWh)} = \frac{\text{Marginal Energy Cost (\$/kWh)}}{\text{Price of Marginal Plant's Fuel (\$/BTU)}}$ | |

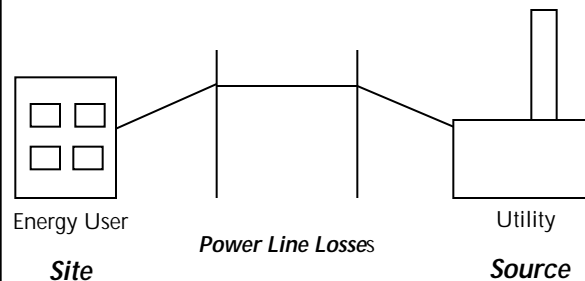
Figure 2-4
Source Energy Savings Formula

$$\text{DSM Program} = \sum_{i=1}^5 (\text{kWh Savings})_i \times (\text{Incremental Energy Rate})$$

Before applying the formula of Figure 2-4 to calculate the source energy savings of TES, one clarification and one simplification should be made. Figure 2-5 shows three components in determining source energy use. The first component is the number of kWhs at the energy user's site. The second component, as discussed previously, is the fuel used at the power plant to generate the kWhs for use at the energy user's site. But a third component is sometimes overlooked.

The third component is the energy used to get the electricity across the power lines from the power plant to the user. In particular, energy is lost due to resistance in the power lines (line losses). For example, to get 1.00 kWh of electricity delivered to the energy user's site, 1.10 kWh may need to be input into the power lines at the power plant. This amounts to a 10 percent line loss. Moreover, an important factor in this TES analysis is that these line losses vary across the five time periods. In particular, line losses are highest when the lines are more fully loaded and when the ambient temperature is hotter. Both of these factors lead to line losses being higher during the summer on-peak period. Therefore, TES saves energy by shifting electricity use to times of lower line losses.

Figure 2-5
Three Components of Source Energy Use



Marginal cost numbers may or may not reflect line losses. In some analyses, the utility is concerned about marginal costs at the power plant (or generation) level. In other analyses, the utility is concerned about marginal costs at the energy user site (or distribution) level.

When calculating marginal costs at the distribution level, the generation level marginal costs are increased to reflect the line losses to the distribution level, as Figure 2-6 shows. When evaluating DSM programs which have their impacts at the energy user's site, the utilities (CPUC and Energy Commission) use the distribution level marginal costs that reflect the line losses.

Figure 2-6
Calculating Marginal Energy Costs
at the Site Distribution Level

$$\begin{aligned} \text{Marginal Energy Cost (\$/kWh at site)} &= (\text{Marginal Fuel's Price}) \\ &\times (\text{Incremental Energy Rate}) \\ &\times (\text{Line Loss Factor}) \\ &= (\$/\text{BTU at Power Plant}) \\ &\times (\text{BTU/kWh at Power Plant}) \\ &\times \frac{(\text{kWh input at Power Plant})}{(\text{kWh output at Site})} \end{aligned}$$

This point is highlighted to show that the source energy savings formula for DSM programs in Figure 2-4 needs to start with marginal energy costs at the distribution level. If not, then the Incremental Energy Rates at the generation level need to be multiplied by the line loss factors to reflect energy usage at the distribution or site level. Indeed, the data provided for this study was Incremental Energy Rates at the generation level — to which line loss adjustments were made to get source energy savings from a kWh change at the site level.

To clearly accommodate the line-loss factors, the source energy savings formula in Figure 2-4 is modified to that shown in Figure 2-7. Note that the formula is the same as in Figure 2-4 except that the Incremental Energy Rate is broken into two components — Incremental Energy Rate at the power plant source and line loss factor to get the energy to the customer site.⁸

Figure 2-7
Final Source Energy Savings Formula

$$\begin{aligned} \text{TES Source Energy Savings} &= \sum_{i=1}^5 (\text{kWh Savings})_i \\ &\times (\text{Incremental Energy Rate}) \\ &\times (\text{Line Loss Factor}) \\ &= \end{aligned}$$

In addition to this clarification, one simplification made the source energy savings calculations easier. The simplification is that the source energy savings are normalized and are assumed to yield no net kWh savings at the site. This is illustrated in Figure 2-8. For example, a kWh “saved” in the summer on-peak period was assumed to be shifted to the mid-peak and off-peak period (where it shows up as increased kWh use).

The same approach was used for the winter— in which all kWh savings during the mid-peak period were assumed to be shifted to off-peak. However, the size of the number of kWhs “saved” during the winter mid-peak was varied to reflect the fact that for different buildings in different locations the winter mid-peak kWhs and summer on-peak kWhs will be a different percentage of the annual kWhs. For example, assume a building site without TES would normally use 30 percent of its annual cooling kWh during the summer on-peak period and 40 percent of its annual cooling kWh during the winter mid-peak period. Also assume the site then installed a full storage TES system and shifted all summer on-peak kWhs and all winter mid-peak kWhs. In this situation, the X in Figure 2-8 would become 1.33 (=40%/30%). If the building used a partial storage system, then maybe only 2/3’s of the summer on-peak kWhs could be shifted. Then the X in Figure 2-8 would become 2 (=40%/(30%*2/3)). In the analysis later in this section, the value of X was varied to reflect a range of building types (e.g., large office, small office and hospital), TES storage systems (full vs. partial), and utility service areas.

| Figure 2-8 Typical TES kWh Shifting Across Time Periods | | |
|--|--|-----------|
| Summer ^a | | |
| On-peak | | -1.00 kWh |
| Mid-peak | | .25 kWh |
| Off-Peak | | .75 kWh |
| Winter | | |
| Mid-peak | | -X kWh |
| Off-Peak | | X kWh |

One of the advantages of making the assumption of no net kWh savings in Figure 2-8 is that it allowed this study to separate the source energy savings analysis from the site (or kWh) savings analysis. A number of other studies have been conducted examining site energy savings, as discussed in the next section. The

Collaborative wanted this source energy analysis to be separated from any analysis of site savings.

This concludes the discussion of the Incremental Energy methodology for calculating source energy savings. This is the methodology most consistent with existing DSM planning and evaluation practices in California. As a point of comparison, however, one other methodology, the Marginal Plant method, was used. This alternate method is further described.

Marginal Plant Method

The Marginal Plant method is the same as the Incremental Energy method with one major difference — a “Marginal Plant” heat rate is calculated to replace the Incremental Energy Rate in the formula in Figure 2-7. In this method, the heat rates implicit in the “system lambda” (or modified system lambda) used by system operators to regulate power plant operation is used. System lambda is the marginal cost per kWh at any particular time to serve an increase or decrease load. System lambda is used to adjust most power plants operating levels up or down so as to minimize production costs while matching generation to the level of electrical demand. If system lambda is divided by the cost of fuel for the marginal power plant, then marginal heat rate numbers can be also derived from it. Alternatively, the heat rate of the marginal plant can directly be determined. The heat rates of the marginal plant were averaged across all hours of a time period to determine the “marginal plant” heat rate for that time period. These heat rates can be compared for the different time periods to determine the source energy savings from shifting a kWh.

Unit Commitment Energy Use — the major difference between the two methods

The CPUC and Commission do not, however, use system lambda (as the Marginal Plant method does) to determine marginal energy costs in their marginal costs analyses for rate design and resource planning. The major reason is that system lambda does not reflect the fuel use required for “unit commitment”. That is, most conventional steam power plants cannot be turned on only during the hour that they are needed. Therefore, a utility often must “commit” some power plants to warm up and operate in the middle of the night even though they are only needed to meet daily peak demand. Leaving the plants running during the night at lower capacity levels uses fuel less efficiently. Lowering the daily peak demand reduces the number of

power plant units that must be committed. Then all other units can operate more fully loaded and, thus, more efficiently.

The fuel efficiency impact of plant loading is illustrated with California utility data submitted to the Commission, as Figure 2-9 shows. The steam plant is quite efficient at full loading with a heat rate of 7,900 BTU/kWh. The heat rate, however, increases (and efficiency decreases) when the plant is run only partially loaded. For example, at a 30 percent loading (130.5 MW) level, the heat rate increases to 11,744 BTU/kWh — almost a 50 percent decrease in efficiency.

Figure 2-9

Typical California Power Plant Heat Rates are Higher at Lower Plant Loadings

| Steam Plant | | |
|-------------------|-------|-------------------|
| % of Full Loading | MW | Heat Rate BTU/kWh |
| 30% | 130.5 | 11,744 |
| 50% | 217.5 | 8,934 |
| 70% | 304.5 | 7,950 |
| 100% | 435 | 7,900 |

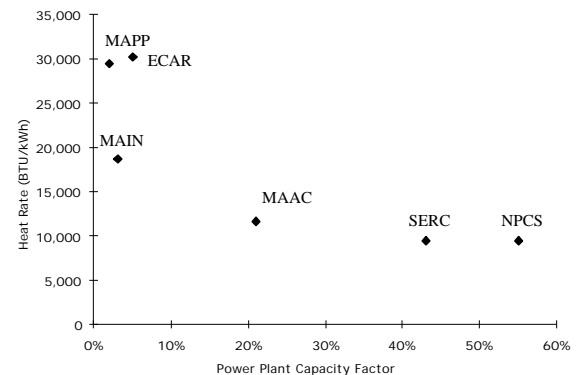
Source: Utility submittals to the California Energy Commission as reported in Primary Source Energy Position Paper by Lennox Industries, August 24, 1994.

This point is further illustrated in Figure 2-10 with regional data on oil steam plant use.¹⁰ Oil steam units are used in different ways in different parts of the country. In the West Central states (such as North Dakota) MAPP Reliability region,¹¹ the steam plants are used mainly to provide spinning reserve. In such situations, the plants may be on and burning fuel to back up other plants or meet daily peaks. Such plants have a low net output or capacity factor and very high net heat rate. In contrast, in the Southeast or SERC region such plants may be used more as intermediate or base load plants. The plants operate more fully loaded most of the time — and have a higher capacity factor and lower heat rate. Figure 2-10 shows considerable variation in 1991, in oil steam plant heat rate — strongly related to power plant capacity factor loading.

Figure 2-10

Nationwide Data Shows 1991 Oil Steam Plant Heat Rates

Source: 1991 FERC Form 1 Data Aggregated by Reliability Regions as reported in Primary Source Energy Position Paper by Lennox Industries, August 24, 1994.



TES helps to improve capacity factor and efficiency in two ways:

- by *reducing* peak demand, fewer power plants must be turned on or “committed” to run and burn fuel.
- by *increasing* the off peak usage, other power plants can operate at higher, more efficient levels.¹²

This concludes description of the methodology. Now the methodology is applied to determine the source energy savings.

Analysis

With the methodology defined, the source energy savings from TES can now be calculated by applying the formula in Figure 2-7 for the SCE and PG&E areas. The source energy savings are calculated first using the Incremental Energy method and then using the Marginal Plant method.

SCE savings — Incremental Energy method

To apply the formula of Figure 2-7, the inputs for the three terms must be determined. As discussed above, to simplify the analysis the inputs for the kWh savings term will be the numbers of Figure 2-8. But the value of X (the ratio of winter mid-peak kWhs shifted to the summer on-peak kWhs shifted) is varied from 0.5 to 4.0 to capture the range of possible load shift ratios, as noted in Figure 2-11.

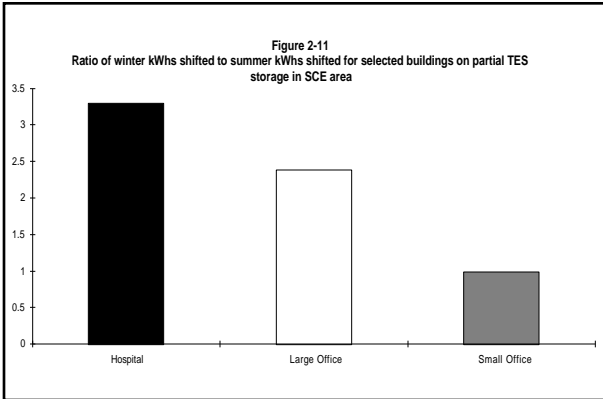


Figure 2-11 shows how the ratio of winter to summer kWhs shifted (X) varies for partial storage systems in three representative building types¹³ —

hospital, typically with a 24 hour per day operation,

large office building, typically with a high internal load and 10-16 hour operation using a central chiller, and

small office building typically using package air conditioning.

For full storage systems, the ratios are about 2/3's this size — since full storage systems can shift all the summer on-peak kWhs.

The second term of concern in the formula in Figure 2-7 is the Incremental Energy Rates by time period. Figure 2-12 shows SCE's projected Incremental Energy Rates at the power plant for 1995. The summer on-peak and winter mid-peak Incremental Energy Rates include fuel use for "unit commitment." Note that the Incremental Energy Rate for the summer mid-peak and off-peak are 38 percent and 46 percent less, respectively, than the Incremental Energy Rate for the summer on-peak period. By comparison, the Incremental Energy Rate of the winter off-peak period is 31 percent less than the winter mid-peak period. These numbers mean TES can save source energy by shifting kWhs in summer and in winter.

Figure 2-12
Relative SCE "Incremental Energy Rates" by Time Period

| | Summer | Winter |
|----------|--------|--------|
| On-Peak | 14251 | ---- |
| Mid-Peak | 8818 | 10714 |
| Off-Peak | 7647 | 7419 |

% Difference by Time Period

| | Summer | Winter |
|----------|--------|--------|
| On-Peak | ---- | ---- |
| Mid-Peak | 38% | ---- |
| Off-Peak | 46% | 31% |

Source: SCE "Marginal Cost" Exhibit documentation for CPUC in General Rate Case for test year 1995. Revised March 1995.

The third term of concern in the formula in Figure 2-7 is the line loss factors. Figure 2-13 shows the relative loss factors used.¹⁴ It shows that the off-peak line losses at the secondary voltage average about 5 percent lower than the line losses during the summer on-peak.

Figure 2-13
Power Line Loss Factors at Secondary Voltage*

| | Summer | Winter |
|----------|--------|--------|
| On-Peak | 1.000 | ---- |
| Mid-Peak | 0.967 | 0.983 |
| Off-Peak | 0.953 | 0.956 |

*Used for both PG&E and SCE.

Source: PG&E 1995 Marginal Cost data submitted to the CPUC for the 1996 General Rate Case

The effect of the differences in Incremental Energy Rate and line loss factors can be combined. Figure 2-14 shows that the combined effect yields a source energy savings of 49 percent for each summer on-peak kWh that is shifted to the off-peak.¹⁵

Figure 2-14
SCE Source Energy Use % Differences
— Incremental Energy Method*

| | Summer | Winter |
|----------|--------|--------|
| On-Peak | ---- | ---- |
| Mid-Peak | 40% | ---- |
| Off-Peak | 49% | 33% |

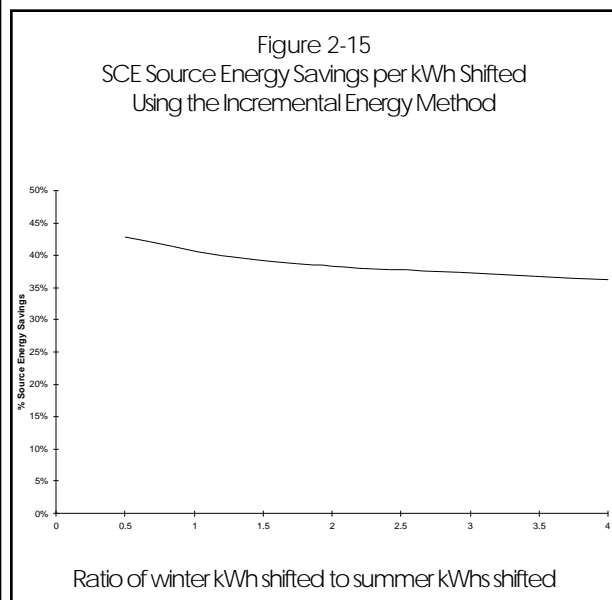
*Incremental Energy Rate & Line Losses Combined

The source energy savings now can be calculated per kWh shifted using the formula in Figure 2-7. Applying this formula yields source energy savings per kWh shifted that varies depending on how many of the kWhs are from the winter vs. the summer. This occurs because the source energy savings from shifting one kWh is lower in the winter than in the summer (see Figure 2-14. Total source energy savings will be lower when the ratio of winter to summer kWh shifted is higher. Figure 2-15 shows this by illustrating how percent source energy savings per kWh shifted varies as a function of the X ratio — winter kWh shifted divided by summer kWh shifted. For buildings like hospitals where the air conditioning typically runs 24 hours-a-day, often 365 days a year, this ratio will be higher — and the percent source energy savings will be lower (e.g., 36 percent). In contrast, for smaller office buildings with package air conditioning or for full storage TES systems, the ratio will be lower — and the percent source energy savings will be higher (e.g. 43 percent).

Air conditioning engineers also will find it useful to characterize this information in an alternate way. The source energy savings can be characterized as a percentage of the source energy required to meet the total annual cooling load. This percentage can be computed by multiplying:

$$\begin{aligned} & \text{\% source energy savings per kWh} \\ & \quad \text{of annual cooling load} = \\ & (\text{\% source energy savings per kWh shifted}) \\ & \quad \times \\ & (\text{\% of annual kWh shifted by TES}) \end{aligned}$$

The first multiplicand — (percent source energy savings per kWh shifted) — comes from Figure 2-15. The second multiplicand — (percentage of annual kWh shifted by TES) — will again vary by TES system. Typically, the second multiplicand will range from about 40 percent for hospitals with partial storage systems to about 65 percent for office buildings with full storage systems.



Multiplying these range of percentages together yields the following range of percent source energy savings per kWh of annual cooling:

- 14 percent, typically for organizations with 24 hour a day cooling and partial storage,
- 28 percent, typically for small office buildings with package air conditioners replaced with full storage.

In summary, the Incremental Energy method for Edison reveals significant source energy savings from shifting kWhs of electricity with TES.

SCE savings — Marginal Plant method

The savings calculations for the Marginal Plant method are essentially the same, except the heat rates used will be different than the Incremental Energy Rates.

Figure 2-16 shows the relative heat rates for the five time periods using the Marginal Plant method. Note that the differences among time periods are lower than under the Incremental Energy method. This is particularly true in the winter time.

Figure 2-16
SCE Relative Marginal Plant "Heat Rates"

| | Summer | Winter |
|----------|--------|--------|
| On-Peak | 1.000 | ---- |
| Mid-Peak | 0.708 | 1.000 |
| Off-Peak | 0.693 | 0.973 |

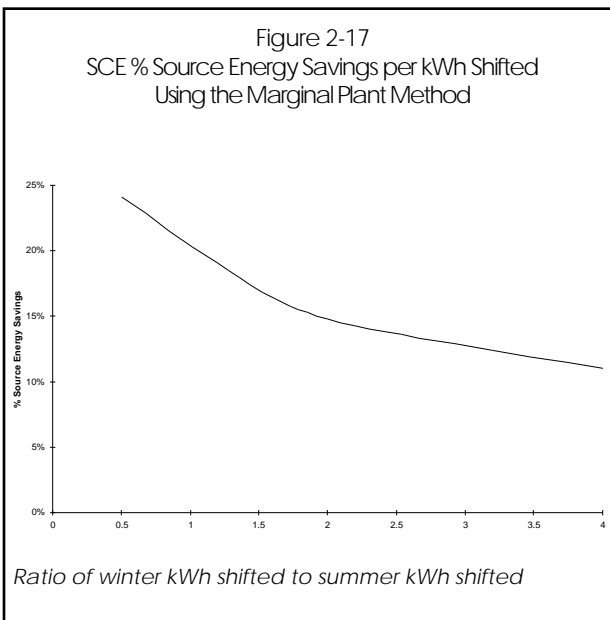
% Difference by Time Period

| | Summer | Winter |
|----------|--------|--------|
| On-Peak | ---- | ---- |
| Mid-Peak | 29% | ---- |
| Off-Peak | 31% | 3% |

Source: SCE System Planning for 1992 and 1993 and FERC Form 1 data.

Applying these heat rate numbers in the formula of Figure 2-7 yields percent source energy savings like those shown in Figure 2-17. These numbers (ranging from 12 percent to 24 percent) are considerably lower than those in Figure 2-15 using the Incremental Energy method. Thus, excluding the impact of fuel used for unit commitment significantly influences the energy savings calculations.

This concludes the source energy analysis for SCE.



PG&E savings— Incremental Energy Method

PG&E's source energy savings can be analyzed in a similar manner using the formula in Figure 2-7. The line loss factors are assumed to be the same (see Figure 2-13). But the savings allocation by time period and the incremental energy rates will be different.

Figure 2-11 showed the ratio of winter peak hours shifted to summer peak hours shifted for SCE. The ratios for PG&E are essentially half of that. The reasonableness of this can be easily seen in noting that the ratio of winter months to summer months for PG&E ($1=6/6$) is half the ratio of winter to summer months for SCE ($2=8/4$).

PG&E does not explicitly calculate Incremental Energy Rates as SCE does. However, PG&E develops comparable marginal energy costs. As Figure 2-3 showed, Incremental Energy Rates (or the relative size of the IER's) can be derived from these generation level marginal energy costs. Figure 2-18 shows PG&E's marginal energy costs and their relative difference by time period. As for SCE, the summer on-peak and winter mid-peak numbers include the effect of "unit commitment."

Figure 2-18
PG&E Marginal Energy (Production) Costs
by Time Period (cents/kWh)

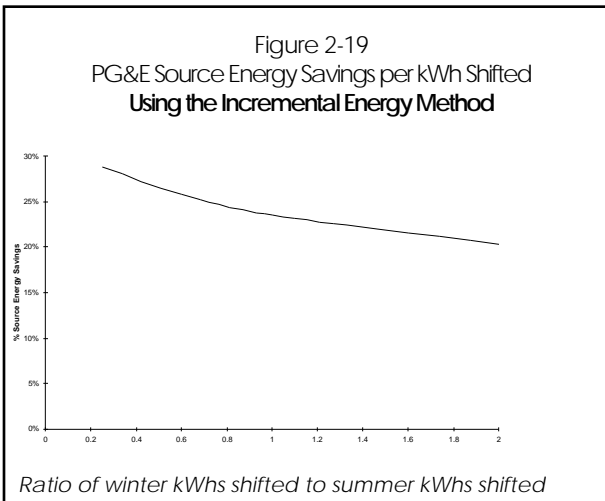
| | Summer | Winter |
|----------|--------|--------|
| On-Peak | 2.81 | ---- |
| Mid-Peak | 2.18 | 2.50 |
| Off-Peak | 1.93 | 2.22 |

% Difference by Time Period

| | Summer | Winter |
|----------|--------|--------|
| On-Peak | ---- | ---- |
| Mid-Peak | 22% | ---- |
| Off-Peak | 31% | 11% |

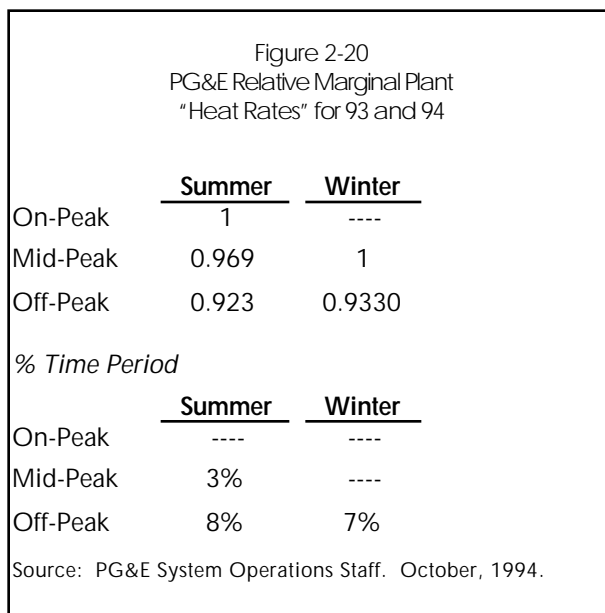
Applying the above numbers to the formula of Figure 2-7 yields the percent source energy savings per kWh shifted shown in Figure 2-19. Some facilities, with a high proportion of the shifted kWhs in the summer (such as small commercial), have source energy savings approaching 30 percent. In other facilities with more constant cooling loads (such as hospitals), the savings approaches 20 percent.

As noted under the SCE discussion, not all cooling kWhs are shifted by TES and sometimes air conditioning engineers find it useful to express source energy savings as a percentage of total air conditioning load. For PG&E, typically 40 percent to 80 percent of the annual cooling energy may be shifted by TES. Multiplying these percentages by the savings per kWh shifted yields the savings per kWh of annual cooling energy. These savings would range from 8 percent to 24 percent of annual cooling energy requirements.



PG&E savings — Marginal Plant Method

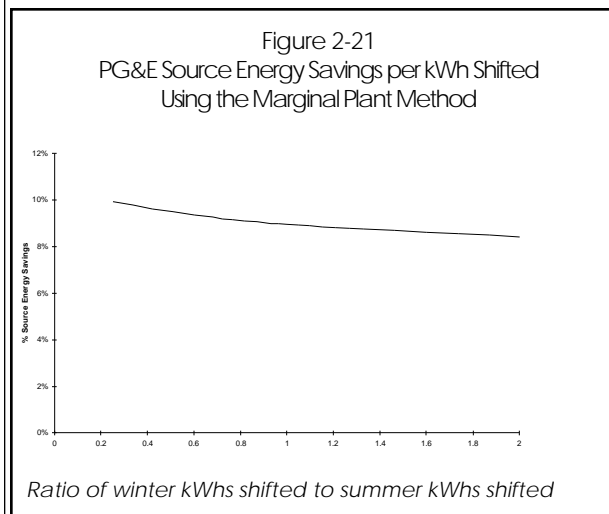
As for SCE, the Marginal Plant method is an alternate way to calculate source energy savings. This method again applies the formula in Figure 2-7, but uses different inputs for heat rate, as Figure 2-20 shows.



When applying these alternate heat rates to the formula, an alternate set of estimates are obtained for source energy savings, as Figure 2-21 shows. These savings show little variation in source energy savings as a function of ratio of winter to summer shifting. The savings estimates vary between 8 percent and 10 percent per kWh shifted.

This concludes the analysis of source energy savings from TES. The savings calculations from the Incremental Energy method are the recommended savings estimates because of the consistency with other California planning and evaluation methods. Such savings were:

- 36-43 percent per kWh shifted for buildings in SCE's area and
- 20-30 percent per kWh shifted for buildings in PG&E's area.



Statewide Potential of Source Energy Savings

To provide some perspective on this value of such savings in California consider the following. Today, the electricity use for air conditioning in California is about 30,000 Gwh. By 2005 it will be close to 36,000 Gwh — which equals the electricity use today for all customers served by the Los Angeles Department of Water & Power and Sacramento Municipal Utility District combined. This is also about 14 percent of total electricity use in California.

If TES achieved an 20 percent market penetration by 2005¹⁶, then about 1300¹⁷ Gwh equivalents of source energy could be saved. Based on Commission's

forecasts, this is enough source energy savings to supply about a fifth of all new air conditioning growth in the next decade — even if TES saves no kWhs of electricity. From another perspective, this is saving enough source energy to supply all electric cars added in the next decade.¹⁸

In summary, TES can provide major source energy savings to California in the next decade if TES systems are properly designed and operated and if TES is aggressively promoted.

Chapter End Notes

¹ “Unit commitment” refers to the system operating practice of “committing” a power plant “unit” to warm up and run for many hours in a day so that it’s available to meet the daily peak demand.

² See, for example, California Public Utilities and California Energy Commission, *Standard Practice Manual: Economic Analysis of Demand-Site Management Programs*. December, 1987.

³ The CPUC also defined the source BTUs of natural gas and other fuels essentially to be those used at the burner tip of the energy user’s equipment, such as a furnace. See CPUC decision D94-10-059 for more details.

⁴ Don Schultz, Personal communication, December 1993, and Scott Logan, Personal communication, June 1995.

⁵ Natural gas is the fuel of the marginal power plant enough of the time that in calculating marginal costs for resource planning decisions it is assumed to be the marginal fuel all of the time. Personal communication, PG&E planner, January, 1995. Also see the working papers to SCE’s Marginal Cost exhibit in the General Rate Case for test year 1995.

⁶ See the working papers to SCE’s Marginal Cost exhibit in the General Rate Case for test year 1995.

⁷ The “kW” terms fall out of the equation in Figure 2-4 since there is no “energy” use associated with them.

⁸ The formula of Figure 2-7 assumes that the TES system is operated under conventional Time-of-Use rates whose time periods match the five time periods of this analysis. TES systems can also be operated with intelligent control systems under hourly varying Real-Time Pricing. Such operation can exploit cost variations within the five time periods. Indeed, in some situations the thermal storage savings of marginal energy costs (and presumably source energy) under intelligent RTP control was almost double the savings under conventional Time-of-Use control. (See, B. Daryanian, L.K. Norford, and R.D. Tabors, “RTP Based Energy Management Systems: Monitoring, Communication, and Control Requirements for Buildings under Real-Time Pricing.” ASHRAE Transactions 1992, V.98, Pt. 1.) The California Public Utilities Commission recommends Real-Time Pricing as the dominant type of pricing in a competitive or restructured electric power industry. Therefore, the source energy savings of TES under the increasingly more common Real-Time Pricing could be significantly

higher than the source energy savings reported here.

⁹ These numbers are based on PG&E’s experience with TES systems. Ken Gillespie, PG&E, Personal Communication, January 1995. Also note that these numbers are changes in kWh use — or the negative of changes in savings.

¹⁰ Each utility across the country must report to the Federal Energy Regulatory Commission on Form 1 what the heat rate was during the previous year for each power plant. Each utility also must report the net kWh output of each power plant. The net kWh output divided by the annual maximum possible output yields the “capacity factor” or annual average plant loading.

¹¹ Often, nationwide data is reported by different regions of the North American Reliability Council (NERC). The data points in Figure 3-12 are data summarized by NERC regions.

¹² Sometimes utilities face the situation where night-time load is so low that efficient base-load units must be turned off and less efficient intermediate plants must be used more. Reducing the occurrence of such situations increases the source fuel savings.

¹³ The allocation of annual air conditioning use across the five time period is based on savings numbers for new high efficiency air conditioning systems found in Southern California Edison Company’s “Demand-Side Management Unit Energy Savings” report of October, 1992.

¹⁴ These line loss factors are PG&E 1995 marginal cost data submitted to the CPUC as part of its General Rate Case filing for test year 1996. Edison’s data is not expected to vary substantially from this.

¹⁵ The percent savings of Figure 2-12 and 2-13 are not additive because of the multiplicative relationship of energy used at the power plant and source energy.

¹⁶ PG&E conducted an internal study — *Off-Peak Cooling Market Potential Study* — that conservatively estimates 20% as an achievable market penetration for TES.

¹⁷ $1300 \text{ Gwh} = (36,000 \text{ Gwh of air conditioning}) \times (20\% \text{ market penetration}) \times (18\% \text{ savings})$ where 18% savings assumes 60% of the state will reflect 20% source energy savings per kWh of cooling like SCE’s and 40% of the state will reflect 16% source energy savings like PG&E’s.

¹⁸ The Energy Commission projects electric cars to use 1618 GWhs in 2005. Personal communication, Lynn Marshall, CEC Demand Analysis Office. August 1995.

Section 3

Other Impacts of Thermal Energy Storage

In addition to the Source Energy savings analyzed in the previous section, several other TES impacts are of concern. These impacts are related to the benefits that the Commission seeks in any technology assisted by Commission's commercialization efforts:

- Site energy efficiency
- Air emissions reductions
- Economic development/competitiveness

These three impacts are individually analyzed.

Site Energy Analysis

Many energy professionals perceive that TES cooling systems require more kWhs to deliver a ton-hour of cooling than conventional cooling systems. There is some basis for this perception. For example, the Electric Power Research Institute monitored some early TES systems in the mid-1980s and concluded that those particular TES systems used more electricity than conventional systems.¹

Certainly, there are some features inherent in TES systems that lead to some inefficiency compared to conventional systems, as listed in Figure 3-1. For example, the system can lose cool energy to (absorb heat from) the outside environment. Also, in transferring the cool energy from the chiller to the storage tank (and then on to distribution system) additional energy can be used. In ice storage systems the ice chillers use more energy than water chillers due to the lower refrigerant temperatures required to produce ice. Finally, if the TES systems are not designed or operated properly (as was many times the case in the 1980s as designers and facility operators learned about the TES technology) then the chiller auxiliary equipment (pumps and fans) could run longer.²

Figure 3-1
TES Site Inefficiency

- Stand-by losses and heat (cool) transfer
- Ice Chiller
- Increased cooling tower and chiller pump/fan operation (if not designed and operated properly)

Over time, the TES designers and operators became more skilled and began to take advantage of some of the features of TES that lead to improved site efficiency as listed in Figure 3-2. One of the main ways that TES systems can provide enhanced efficiency is by having the chillers (and their supporting pumps and fans) run fully loaded most of the time at their peak efficiency. As noted in the previous section, the chillers and support equipment of conventional cooling systems must run whenever the building occupants want cooling. The chiller system capacity is sized for the peak (or design) cooling day. Most of the year, however, the chiller system does not operate near peak cooling conditions in California, as Figure 3-3 shows. In fact, about half of the year the typical chiller system operates at less than 30 percent of capacity. At such low capacity loading, the energy efficiency of a conventional chiller system decreases — or its energy intensity (kWh/ton-hour of cooling) substantially increases, as Figure 3-4 shows.³ Thus, much of the year a conventional chiller system can operate an energy intensity that is 2-4 times higher than its design intensity. Many analyses showing that conventional cooling systems are more efficient than TES systems have not adequately captured the increased energy use of partially loaded conventional systems.⁴

Figure 3-2
TES Site Efficiency

Chiller

- Fully loaded
- Cooler nighttime temperatures
- Enhanced heat recovery
- Free (economizer) cooling in winter
- More efficient than rooftop (unitary) units

Distribution System

- Lower volume of cooler water/air is moved by pumps/fans
- Lower humidity can allow higher indoor temperatures

In well-designed TES systems, the chiller system almost always operates fully loaded. By having a set of chiller (primary) pumps that operate separately from the distribution system (secondary) pumps, the chiller and its pumps can run at efficient fully loaded levels. Thus, the more frequently that the cooling load is less than design capacity, the better that TES looks compared to conventional cooling systems.⁵

Figure 3-3
California Cooling Systems Often are Not Fully Loaded

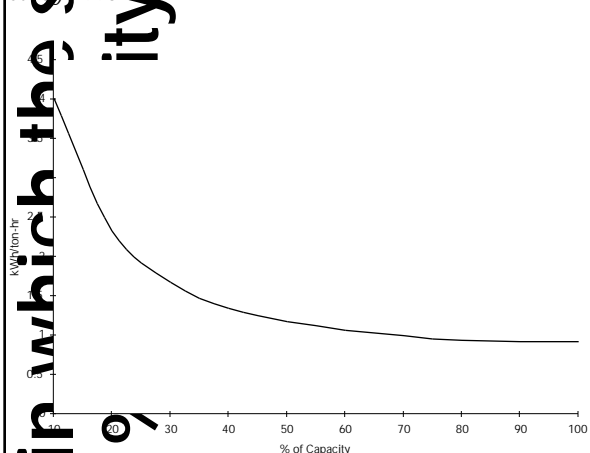
Source: PG&E DOE-2 Analysis, 1995

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Figure 3-4
Conventional Centrifugal Chiller Systems
Energy Intensity Increases When Partially Loaded

Source: TGK Consulting "EPA/NRDC Chiller System EER Study, 1995"



In addition to operating more fully loaded, TES offer several other opportunities for improving efficiency. For example, TES chillers running at night are more efficient. Related to this, some places in California require daytime cooling in the winter but may have nighttime temperatures in the low 40s. Running the cooling tower without the chiller may allow a chilled water or eutectic salt storage system to be charged with almost “free” cooling, using 85 percent to 90 percent less energy ⁶ than a conventional cooling plant.

When Not Operating at Design Capacity

- Conventional cooling efficiency usually decreases.
- TES can be more efficient.

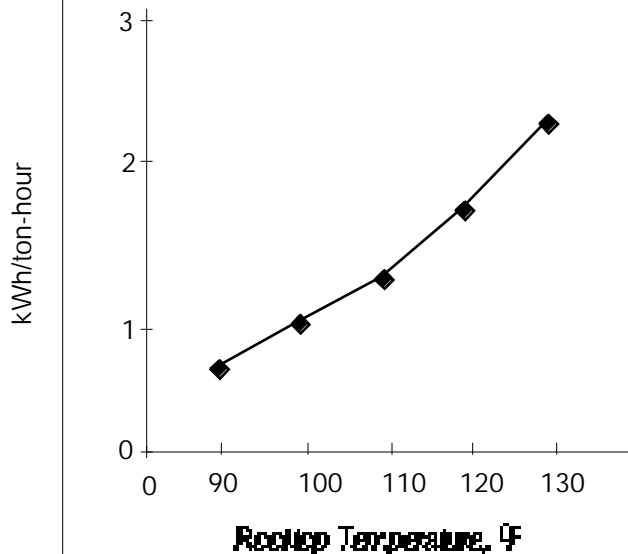
Another efficiency gain that thermal storage facilitates is waste heat recovery. That is, the “waste heat” from the chillers is captured and used to supply hot water to the building. Separate storage for hot water again allows the supply of hot water to be generated at times other than when demanded. This has enhanced the feasibility of chiller waste heat recovery — in residential buildings as well as commercial buildings.

Another efficiency gain is more applicable for small commercial buildings and single-family residences. Such structures typically use unitary air-cooled, direct expansion split systems or single-package rooftop units to provide cooling rather than chilled water systems. The unitary systems are typically 10 percent to 50 percent more energy intensive under normal conditions. Even worse, the energy intensity of the rooftop units increases as the rooftop temperature increases as Figure 3-5 shows. Indeed, PG&E has found that on hot summer days rooftop temperatures of 130°F are not uncommon and energy intensity can increase by 70 percent. Of greater concern to the building owner is that the cooling capacity of the air conditioner then decreased by 40 percent.

In addition to enhancing chiller, TES also can enhance distribution system efficiency. Such enhanced efficiency is achieved through cold air distribution. As described in Section 1, colder supply air into the distribution system means that a smaller volume of water and air must be moved to achieve the desired cooling. A smaller volume of water and air requires (up to 40 percent⁷) less energy to move — either through smaller pumps and fans or through adjustable speed drives on pumps and fans.

Figure 3-5
Rooftop Air Conditioner's Energy Intensity
Increases significantly with Temperature

Source: ARI test data supplied by PG&E



In addition to enhancing chiller performance, TES also can enhance distribution system efficiency. Such enhanced efficiency is achieved through cold air distribution. As described in Section 1, colder supply air into the distribution system means that a smaller volume of water and air must be moved to achieve the desired cooling. A smaller volume of water and air requires (up to 40 percent⁸) less energy to move — either through smaller pumps and fans or through adjustable speed drives on pumps and fans.

Another factor can lead to greater energy efficiency in the distribution system. Colder air holds less moisture (i.e., is less humid). When it is added to the occupant area, it leads to less humid conditions than from conventional supply systems. The lower humidity can mean the temperature can be raised and the occupants will be just as comfortable.⁹ The higher cooling temperature means even less cold air is needed.

This concludes a quick overview of how TES systems have inherent opportunities for system efficiencies as well as system inefficiencies. Now some case studies of where TES systems have achieved net kWh efficiencies are summarized in Figure 3-6.

Figure 3-6
TES Site Efficiency Case Studies

| Building | Location | TES Size (ton-hours) | Partial/ Full | New/ Retrofit | Summer kWh Savings | % Cooling kWh Savings | *Method | Source | Comments |
|--|-----------------|----------------------|---------------|---------------|--------------------|-----------------------|---------|--------------------------------|-----------------------------------|
| Commercial-Industrial | | | | | | | | | |
| Chilled Water Storage | | | | | | | | | |
| Electro-Optics Plant | Dallas, TX | 24500 | F | R | 2900 | 12% | M, B | Energy Engineering, Vol. 89, 4 | heat recovery |
| University | Fullerton, CA | 40000 | F | R | 3360 | 13% | S | Brown & Caldwell | heat recovery |
| University | Tempe, AZ | | | R | 7000 | 13% | B | ITSAC, Tech Bulletin, 1-92 | |
| College | Houston, TX | 4000 | | R | | 8-9% | B | CBI, ASHRAE, 6-93 | |
| Prison | Lancaster, CA | 12600 | | N | | 15-25% | S | ITSAC, Vol. 5,4 | LTD water & water side economizer |
| Supermarket | Miami, FL | | | | | 17% | | EPRI, CU-3031 | |
| Data Processing | Bloomington, IL | 44800 | | N | 5400 | 3% | S | CBI, ASHRAE, 6-93 | |
| Chilled Water replacing rooftops | | | | | | | | | |
| Assembly | Windsboro, SC | 7500 | | N | | 44% | S | ITSAC, Vol. 5,3 | |
| Ice Storage with Cold Air Distribution | | | | | | | | | |
| School | Morristown, PA | 720 | P | N | | 30% | B | ITSAC, Vol. 9,6 | includes Energy Mgmt System |
| Office | Chicago, IL | | | | | 5-15% | B | ITSAC, Vol. 9,5 | |
| Office | | 2000 | P | N | 400 | 6-14% | S | BAC Bulletin: Case Study 3-6 | |
| Ice Storage replacing Rooftop/Unitary Systems | | | | | | | | | |
| Office | Vincennes, In | 25 | P | | 7 | 16% | M | EPRI, TR-101038 | |
| Assembly | Granston, RI | 3000 | F | R | 700 | 50% | B | ITSAC, Vol. 9,6 | |
| School | Cherry Hill, NJ | | P | R | | 12% | M | EPRI | |
| Residential | | | | | | | | | |
| | Richmond, VA | | F | N | 3 | 12% | M | Virginia Power | heat recovery for hot water |

Note: S = Simulation
M = Metered Data
B = Bill Comparison

Site Efficiency Case Studies

In chilled water storage systems, site cooling efficiencies of 10 percent to 15 percent have often been achieved. One system (prison in Lancaster, California) achieving significantly higher savings used a large temperature differential (ΔT) between supply water (40°F) and return water (70°F) and a water-side economizer. Another system (university in Tempe, AZ) achieved significant savings by adding secondary pumps at the same time as the storage tank to achieve significant savings in the operation of the primary chiller pumps.

The above case studies all included a TES tank in a chilled water cooling system. In one case study a chilled water TES system was used in lieu of rooftop units — with projected savings near 44 percent.

Some ice storage systems with cold air distribution have achieved site efficiencies approaching those of chilled water central systems. Ice systems replacing rooftop systems in areas with lower rooftop temperatures than California typically have achieved site efficiencies comparable to those of central chilled water TES systems and better than conventional systems.

Finally, some residential TES systems have been used that include heat storage and heat recovery for hot water as well as cool storage. In some instances they have achieved kWh savings.

Statewide Potential Site Energy Savings

Aggregate potential site efficiency savings can be estimated from this information. In particular, Section 2 showed that there was about 36,000 GWhs of air conditioning load in 2005. Suppose the 12 percent potential site efficiency could be achieved at 20 percent of the installations. Then 15 percent of the electricity required to supply new air conditioning load in the next decade could come from these site efficiency improvements. If site efficiency and source energy savings are combined, then 20 percent penetration of TES can supply over a third of the energy needs of new air conditioning in the next decade.

In summary, the TES community is evolving. In an increasing number of instances, site efficiency improvements have been achieved along with load shifting. If California supports the design and building operator communities in the use of TES, California could expect to see continued site efficiency improve-

ments from TES systems. With this analysis of site efficiency complete, air emission impacts are analyzed.

Air Emission Analysis

TES can potentially reduce air emissions at the power plant source and the building site. The following analysis first considers source impacts and then site impacts.

Air Emissions Impacts at the Power Plant Source

As for the Source Energy analysis, information from the utilities' marginal cost submittals in the General Rate Case filings with the PUC can be helpful in determining the air emissions impacts of TES. Figure 3-7 shows how PG&E's power plant air emissions costs vary by time period. As in the Source Energy analysis, by recognizing that a natural gas fired power plant is usually the marginal plant, the percent difference in costs between time periods reflect the percent difference in air emissions.

Figure 3-7 shows that the air emissions savings from shifting a kWh are slightly higher than the source energy savings. For example, Figure 3-7 shows a 47 percent savings in emissions by shifting a kWh of cooling load from on-peak to off-peak. By contrast, the source energy savings were only 35 percent. Three factors could explain these higher savings. The first factor is that emission free hydro power may have been on the margin off-peak for part of the year. The second factor is that utilities usually have less stringent emission control measures on power plants that operate fewer hours — such as those used mainly for summer on-peak hours. The third factor is that the marginal off-peak power may have been purchased from another utility. In this limited scope project, the relative importance of these three factors could not be determined. Therefore, the air emissions savings are assumed to be the same as the source energy savings — shown in Figures 2-18 and 2-19.

| Figure 3-7 PG&E Power Plant Air Emissions Costs by Time Period | | |
|---|---------------|---------------|
| • Emission costs (cents/kWh) | | |
| | <u>Summer</u> | <u>Winter</u> |
| On-Peak | 1.142 | ---- |
| Mid-Peak | 0.788 | 0.620 |
| Off Peak | 0.610 | 0.519 |
| • % difference by time period | | |
| | <u>Summer</u> | <u>Winter</u> |
| On-Peak | ---- | ---- |
| Mid-Peak | 31% | ---- |
| Off Peak | 47% | 16% |
| Source: PG&E Working Paper for Marginal Cost exhibit before CPUC in General Rate Case for Test Year 1996. | | |

The emission information from SCE's General Rate Case filing further reflects the importance of these three factors. Figure 3-8 shows SCE's environmental cost information. SCE took a different approach to calculating the cost emissions than PG&E. SCE had the fortunate situation in which the RECLAIM market for trading air emissions by the South Coast Air Quality Management District (SCAQMD) allowed SCE to put a true market value on the emissions rather than an imputed cost. Therefore, SCE chose to use the market approach. The main drawback for this TES analysis is that the SCE power plants and purchased power from other utilities that supplied the marginal kWhs off-peak often was outside of the SCAQMD area. Therefore, the third factor played a larger role. This leads to amazing results in which shifting a kWh from on-peak to off-peak in the summer can lead to a 97% reduction in air emissions in the SCAQMD area.

In that the SCAQMD is one of the most critical air basins in the world, any action that can help that air basin is of positive benefit. On the other hand, it is beyond the scope of this study to trade off the value of decreasing air emissions in one air basin with the value of increasing air emissions in another air basin. Therefore, the conservative path is chosen of assuming that the percentage air emission savings from shifting a kWh follows the percentage source energy (or fuel) savings from shifting a kWh. For SCE these percentages are reported in Figures 2-13 to 2-15.

| Figure 3-8 SCE Power Plant Air Emissions Costs by Time Period | | |
|--|---------------|---------------|
| • Emission costs per RECLAIM credits (mills/kWh) | | |
| | <u>Summer</u> | <u>Winter</u> |
| On-Peak | 0.035 | ---- |
| Mid-Peak | 0.006 | 0.013 |
| Off Peak | 0.001 | 0.001 |
| • % difference by time period | | |
| | <u>Summer</u> | <u>Winter</u> |
| On-Peak | ---- | ---- |
| Mid-Peak | 83% | ---- |
| Off Peak | 97% | 92% |
| Source: SCE Working Paper for Marginal Cost exhibit before CPUC in General Rate Case for Test Year 1995. | | |

Other studies have documented the air emissions savings of TES. For example, a study in the United Kingdom found that TES systems could reduce CO₂ by 14 percent to 46 percent by shifting load off-peak.¹⁰ An EPRI co-sponsored analysis of TES in TU Electric's system found that TES could reduce CO₂ by 7 percent over conventional electric cooling technologies.¹¹

Statewide Potential of Power Plant Emission

The potential aggregate emission savings at the power plant from TES is significant. Data from the CEC indicates that PG&E's existing gas plants will produce about 0.13 lb. of NO_x and 33 lbs of CO₂ per mmBTU of fuel burned and that SCE's existing gas plants will produce about 0.05 lbs of NO_x and 33 lbs of CO₂ per mmBTU of fuel.¹² Assuming that TES installations burned and that SCE's existing gas plants will produce about 0.05 lbs of NO_x and 33 lbs of CO₂ per mmBTU of fuel.¹³ Assuming that TES installations save an average of 6 percent of the total cooling BTUs¹⁴ implies that TES could save about 560 tons of NO_x and 260,000 tons of CO₂ annually statewide.

As a point of perspective, TES in the South Coast Air Quality Management District Air Basin would reduce about 1.6 tons of NO_x per day (although some of this is shifted to other basins.) Based on CEC staff estimates, these savings could be worth \$32 million per year in NO_x credits in the SCAQMD.¹⁵ This 1.6 tons is about a tenth of the total NO_x emissions from all Edison gas

fired plants.¹⁶ It also represents the NOx emissions savings from using 100,000 electric vehicles in the SCAQMD area.¹⁷ Thus, TES can make substantial contributions in reducing air emissions.

Air Emission Impacts at the Building Site

Thermal Storage can affect air emissions at the building site in two ways. First, it can affect the amount of ozone-depleting CFC's or HCFC's in chiller refrigerants. Second, it can affect the amount of combustion emissions used in fuel-fired heating and costing equipment. Each of these impacts is considered.

TES helps reduce CFC's in two ways. First, cooling systems with TES require less chiller capacity than conventional systems. Using fewer or smaller chillers means less refrigerant is necessary. Second, when existing chillers are converted to more benign refrigerants, there can be a loss in cooling capacity. Using TES can off-set this lost cooling capacity — making building operators more willing to switch refrigerants.¹⁸

Thermal Storage has been used to reduce air emissions at the building site. For example, at California State University at Fullerton, a waste heat recovery storage system as an adjunct to a larger TES system allowed the replacement of an old boiler system. This conversion was co-funded by the South Coast Air Quality Management District in Southern California. Moreover, the District recognizes thermal storage as an air emissions control measure.¹⁹

Economic Development/Competitive Impacts

The last major impact of concern to the Commission is enhancing the economic development potential of California. That is, the Commission wants technologies that will help California businesses and energy utilities be more competitive. The following page considers TES ability to provide such economic benefits.

TES provides several economic benefits to electricity. The first major benefit is lower operating or production costs. Recall that the Incremental Energy method used in the Source Energy calculations is also used to calculate the marginal energy costs. Thus, the utility is not only reducing its source energy requirements by 20 percent to 43 percent per kWh shifted with TES, it is also reducing its marginal energy costs of producing a kWh by 20 percent to 43 percent.

Economic Impacts: Electricity suppliers

- * Lower production / operating costs.
- * Improved asset utilization/reduced T&D capital expenditures.
- * More competitive prices.

A second major benefit is improving the capital asset utilization of electric suppliers. The electricity supply industry is one of the most capital intensive industries in the US. It requires almost five times as many dollars of capital to generate a dollar of revenue as the average US manufacturing industry. Therefore, financial analysts know that the load factor of an electricity supplier (generation, transmission or distribution) is a key indicator of the supplier effectively using its capital assets.

TES provides the capability to improve the load factor of many commercial facilities by 30 percent to 50 percent. That means an electricity supplier can reduce its capital intensity (expenditures) in serving such customers by 30 percent to 50 percent, huge capital savings. Indeed, to capture these capital savings in Switzerland, some conditions of service for large commercial buildings strongly encourage thermal storage.²⁰ Such capital savings could become increasingly important in California as electricity suppliers move from an era in which they are rewarded for investing *more* capital (under traditional rate base regulation) to an era in which they will be rewarded for investing *less* capital (under performance based ratemaking regulation).

Statewide Potential Economic Savings

The potential aggregate peak demand savings of TES is significant. The potential new growth in air conditioning load in the next decade is about 2500 MW. Air conditioning is currently about 14,000 MW or about a third of the total peak demand in California. TES in 20 percent of buildings by 2005 could reduce air conditioning load by 2500 MW — off setting all new growth in air conditioning load over the next decade. If most of these TES installations are targeted for new construction or T&D constrained areas, then TES could save over a billion dollars of investment in the T&D system and perhaps equal savings in generation capacity investment.²¹ This translates into savings for utility stockholders and California energy users alike.

Combining the operating cost savings with the capital cost savings means TES can help electricity suppliers

significantly reduce its over-all costs. Since marginal fuel and capacity related costs are about 30 percent to 40 percent of an electric utility's total costs, reducing those by 30 percent for TES customers means the electric utility can shave 9 percent to 12 percent off its total costs in serving such customers. Some California utility CEOs have set objectives of shaving total cost by 5 percent in nominal dollars (or about 25 percent in real dollars) over the next five years. Certainly TES can be one tool in achieving such cost reductions.

Of course, the main reason California utility CEOs are interested in shaving costs is so that they can provide more competitive prices. Today, a large commercial customer typically pays about \$.16/kWh²² for air conditioning in the summer. If the customer properly uses TES, then the costs could be reduced to \$.08 - \$.12 per kWh, depending on the storage system and customer. This amounts to a 25 percent to 50 percent reduction in the cost of air conditioning. Since air conditioning is often 30 percent to 40 percent of the load in a large commercial facility, TES could allow a utility to sell power for 8 percent to 20 percent less. Thus, TES can help provide lower, more competitive prices — with considerable cost savings to make the lower price more profitable.

Not only do utilities or energy suppliers receive economic benefits from TES, so do building owners (or occupants). The first major benefit is lower energy costs. As noted previously, the power bill for air conditioning could be reduced 25 percent to 50 percent with TES. With a targeted 20 percent market penetration by 2005, TES could save over a half billion dollars annually in power costs. Moreover, some commercial facility managers believe that TES could be the best tool available for lowering power costs under Real-Time Pricing in a re-structured electricity industry.

TES is the best tool a commercial facility manager has for managing power costs under Real-Time Pricing, which the CPUC has proposed as the dominant type of pricing in a re-structured electricity industry.

—Bill Kane, Energy Management Coordinator,
San Francisco Moscone Marriott Hotel
—Ted Bischak, Senior VP, Tooley & Co.,
which manages several million square feet for
The Irvine Company

One TES benefit that a number of building owners have appreciated is the ability of TES to increase the property value of a building. The property value increase could amount to \$10-20 billion (in today's

dollars) by 2005. This has allowed building owners to obtain more external financing when purchasing, building or improving a facility. That is, they often needed *less* of their own *cash up-front* rather than more when installing TES. This has been an attractive feature of TES.²³

Economic Impacts: Building Owner

- * Lower energy costs (half billion dollars annually)
 - * Higher property values (\$5 billion)
 - * Increased external financing (\$3-4 billion)
 - * Increased leasable floor space (cold air distribution)
 - * Improved tenant comfort (less humidity)
 - * Lower fire insurance costs (chilled water)
-

TES has also helped building owners increase the revenues from their facilities. In particular, as noted in Section 1, cold air distribution systems require smaller ducts for air distribution. The smaller ducts can mean lower floor-to-floor heights — which allow architects to design additional floors without increasing building height. The additional floors mean more leasable floor space and greater revenues.

TES can also make the space more attractive and leasable by increasing tenant comfort. That is, cold air distribution means less humidity is supplied to the space, as noted in Section 1. Most people find the drier air to be more comfortable.

Finally, chilled water TES systems have allowed some building owners to have lower fire insurance costs. The large storage tank of water is viewed by the insurance companies as additional fire protection. In return, such companies have lowered the fire insurance premiums at some facilities.

This information shows that TES provides several economic benefits to increase the competitiveness of both California utilities and California building owners. This increased competitiveness could enhance the economic development opportunities for California with an appropriate strong TES program.

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DT Reindl, Thermal Storage Applications Research Center, *Characterizing the Marginal Basis Source Energy Emissions Associated with Comfort Cooling Systems*. Report No. TSARC 94-1, December 1994.

¹ Electric Power Research Institute, *Operation and Performance of Commercial Cool Storage Systems*, Vol. 1: 1987 Cooling Season and Vol. 2: 1988 Cooling Season. CU 6561, 1989.

² The experience and motivation of the building engineer is a problem for conventional cooling systems as well as TES. See Richard Sterrett's *Operator Influence on the Performance of Chillers and Thermal Energy Storage Systems*. *Energy Engineering*: 89,4. 1992. p. 66.

³ Field measurement of many chiller systems by the Energy Engineering Institute of San Diego State

University lead to a curve like that in Figure 3-6. See K. Liu et al. *A Comparison of the Field Performance of Thermal Energy Storage (TES) and Conventional Chiller Systems*, *Energy*: 19,8, 1994. p. 889. A major reason that the energy intensity increases is that the chiller pumps and (to some extent) cooling tower typically operate at full load energy use levels even though they are providing significantly less cooling.

⁴ Liu et al. See footnote 24 for a fuller citation.

⁵ Of course, some things can be done to conventional systems to solve the inefficiency caused by partial loading. The first is to have multiple smaller chillers that can be operated in a staged sequence. For example, if a building has two chillers each sized at 50 percent of the building cooling requirements, then when faced with a cooling load of only 50 percent of capacity, only one chiller needs operate at a full efficiency level. A second solution to the partial loading problem is to have variable speed drives on the chiller and its pumps. Then the electricity usage of the chillers and pumps tends to track the cooling demand. Offsetting this, some observers note that for the cost of installing multiple chillers or putting variable speed drives on the chillers and pumps some buildings can pay for much of a TES system. In addition, many building owners today with dual chillers often size each so that they could carry the full cooling load — a high value is placed on cooling system reliability. In actual practice, PG&E, for example, has found a number of chiller systems operating at much higher than their design energy intensities.

⁶ Scot Duncan, Personal communication. June, 1995.

⁷ Some have seen savings as high as 80 percent. Scot Duncan, Personal communication. June, 1995.

⁸ Some have seen savings as high as 80 percent. Scot Duncan, Personal communication. June, 1995.

⁹ ASHRAE has well documented that the comfort in a room is determined by the enthalpy (or total heat content) in the room. The enthalpy is determined by two factors — the temperature and the humidity. (Clearly people in California understand this concept — they are more comfortable in their desert dry heat of 100°F than they are when they visit on a 90°F day in humid New Orleans.)

¹⁰ CB Beggs, *Ice Thermal Storage: Impact on United Kingdom Carbon Dioxide Emissions*. Building Services Engineering Research and Technology 15(1), 1994.

¹¹ DT Reindl, Thermal Storage Applications Research

Center, *Characterizing the Marginal Basis Source Energy Emissions Associated with Comfort Cooling Systems*, Report No. TSARC 94-1, December 1994. The methodology used in this analysis defined “source” differently. In particular, it took source to include the place where the fuel for the power plant was extracted. Thus, it considered the emissions not only at the power plant, but also in extracting and transporting the fuel to the power plant. This definition of source was used to also provide a “source” emissions comparison to natural gas cooling systems.

¹² Angela Tanghetti, California Energy Commission, Personal Communication, June 1995. Edison’s new gas plants emit about 0.09 lbs of NOx per mmBTU.

¹³ Angela Tanghetti, California Energy Commission, Personal Communication, June 1995. Edison’s new gas plants emit about 0.09 lbs of NOx per mmBTU.

¹⁴ A 30 percent reduction from both load shifting (18 percent) and kWh reductions (12 percent) per site with an assumed 20 percent market penetration by 2005 yields of 6 percent total source BTU’s used for cooling.

¹⁵ CEC staff testimony, “RECLAIM Trading Credit, SO₂ Allowance, and Offset Costs” April 14, 1994. CEC Docket 93-ER-94.

¹⁶ Angela Tanghetti, California Energy Commission, Personal Communication, June 1995.

¹⁷ The Air Resource Board has adopted standards for new gasoline automobiles of 0.4 grams of NOx per mile. CEC Staff assume electric vehicles will displace vehicles traveling about 15,000 miles per year. At a cost of \$15,000 per electric vehicle, it would require \$1.5 billion (assuming TES costs about \$600/kW) worth of electric vehicles to save the same amount of NOx as TES systems costing half that amount.

¹⁸ DP Fiorino, *Thermal Energy Storage Program for the 1990s* **Energy Engineering** 89,4, 1992. p. 23

¹⁹ There has been a lot of discussion among regulatory bodies and gas and electric utilities about the trade-offs between site emissions of gas equipment and the source emissions of power plants. It is beyond the scope of this paper to fully engage in that discussion. This study recognizes that at least the South Coast Air Quality Management District has decided that thermal storage with heat recovery is a net plus in its District.

²⁰ For example, the Geneva Electric Utilities Article

117A requires in any building over 10 kW demand that “the installation must be designed to limit the maximum needed power by cutting excessive thermal charges.” Moreover, the designs reviewed by a commission must analyze the possibility of thermal storage and waste heat recovery. One TES manufacturer reports that this rule “helped our sales dramatically in that localized area.” Mark McCracken, CALMAC, Personal communication. July, 1995.

²¹ The capital savings on the Transmission and particularly Distribution system usually are best captured when TES is installed in New Construction rather than Retrofit situations. Thus, the T&D benefits from TES installations can vary from zero in some areas to nearly \$2000 per kW in other areas. In a conventional utility environment, there could be equal or greater savings in the generation side of the business. However, with the advent of de-regulation in the generation, many feel that few power plants will be built for capacity reasons in the next decade.

²² PG&E analysis.

²³ Eric Hafter, ELH Development Services, Inc. Presentation to CEC TES Collaborative. August, 1994. The installed cost of the storage system is assumed to be \$600 per kW of storage for a total investment of \$1.5 billion. Because of the increase in property values, however, a TES investment could net building owner \$3-4 billion in additional cash from financial institutions rather than requiring internal financing.

Section 4

Conclusions

TES provides major compelling benefits of concern to the California Energy Commission:

- Energy efficiency (source and site)
- Environmental (air emissions and CFC)
- Economic development (increased competitiveness of California energy suppliers and energy users).

For these reasons, the Commission and other energy/environmental institutions should consider policy actions that will encourage the market penetration of TES. Possible policy actions are further suggested.

Possible Policy Actions

Based on the energy savings and other benefits of TES, several possible policy actions emerge for consideration. The first possible policy action is deeming TES as a priority energy efficiency or Demand-Side management program in state energy resource policy decisions. TES has demonstrated significant energy and air emission savings like other energy efficiency programs. But unlike most energy efficiency measures, TES significantly improves load factor and provides cost savings that help both energy users and energy suppliers be more competitive.

Possible Policy Actions to Promote TES

- * Deem TES a priority DSM technology in energy policy decisions.
- * Modify Title 24 Building Standards to reflect TES' source energy savings and peak demands reductions.
- * Use TES as an air emissions measure statewide.
- * Identify TES as a priority option for new and replacement cooling systems in "competitive energy environmental partnerships" with key energy users, such as:
 - local, state, and federal buildings, and
 - businesses striving to be environmental leaders, as in the EPA's Energy Star Program.

The second possible policy action is to modify the State of California Title 24 Building Standards method of comparing alternative cooling technologies' energy efficiencies. Currently the standards provide no energy savings credit (or penalty) to TES. The Commission could re-examine the role of source energy comparisons of alternative systems including the opportunities of TES systems. In addition, as in Switzerland, the building code could encourage designers to lower the building peak demands.

The third policy action is recognizing TES as an effective air emissions control measure. The South Coast Air Quality Management District has recognized thermal storage as a way to reduce site emissions. Other air districts could follow suit. In addition, many California air districts would benefit from encouraging TES as a control measure for power plants emissions.

The fourth policy action is promoting TES as a priority cooling system option in "environmental partnerships" with key energy user groups. One such group could be "sister" governmental agencies of the CEC, including local, state, and possibly federal government agencies. Another possible group includes businesses striving to be "environmental partners." As an example, the US Environmental Protection Agency has had considerable success in obtaining business "environmental partners" in its Energy Star programs such as Green Lights. This program has obtained a number of business partners in California who have committed to installing high efficiency lighting in 90 percent of their floor space over a five year period when the internal rate of return (IRR) exceeds 20 percent. California could develop a "Competitive Electricity Environmental Partnership" program for TES that is modeled after the Energy Star program. This partnership would position California businesses to benefit from a competitive electricity market and help clean the air as well. Alternatively, perhaps TES could be included as a priority cooling technology in the second phase of the Energy Star

program — which moves from lighting to heating and air conditioning system improvements.

Sample Organizations in EPA Energy Star/Green Lights Program that have a Significant California Presence

- Allergan*
- ARCO
- Bank of America*
- Calif State University System*
- State of California*
- The Shorenstein Company
- TransAmerica
- Wal-Mart*
- Walt Disney Studios*
- Long's Drugs
- McDonald's*
- Rockwell*
- SCAQMD
- Chevron*
- Embarcadero Center*
- Hewlett Packard*

**Organizations that had TES installed at least one site.*

In summary, the Commission initially believed, and this study confirms, that TES is an “energy technology offering compelling energy, environmental, diversity, and economic development benefits to California.” Moreover, TES is now poised for full commercialization. Institutional policies such as those identified, can be pursued to “effectively increase the market penetration” of TES — as the Commission desires.

Appendix A

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